HEADLEE

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SOME RECENT ADVANCES IN KNOWLEDGE .. AND CONTROL OF MOSQUITOES

ndlee, Thomas J.

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SOME RECENT ADVANCES IN KNOWLEDGE OF THE NATURAL HISTORY AND THE CONTROL OF MOSQUITOES

NEW JERSEY

AGRICULTURAL

Experiment Stations

BULLETIN 306

New Brunswick, N. J.

NEW JERSEY AGRICULTURAL EXPERIMENT STATIONS

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BULLETIN 306

OCTOBER 17, 1916

SOME RECENT ADVANCES IN KNOWLEDGE OF THE NATURAL HISTORY AND THE CONTROL OF MOSQUITOES

BY

Thomas J. Headlee, Ph. D.

DISTRIBUTION

Ever since the publication of the late Dr. John B. Smith's[1] report on the mosquitoes of New Jersey we have known that the brown salt-marsh mosquito *Aedes cantator* Coq., is dominant in early spring along the northern two-thirds of the state's Atlantic coastline and that it gives way from mid-summer, or in some cases late summer, on, to the white-banded salt-marsh mosquito (*Aedes sollicitans* Wlk.). More recently it has been discovered that the former apparently predominates in the southern one-third also, early in the season, and that it is practically the only species which breeds on the northern portion of the Hackensack Valley salt marsh. This peculiarity of distribution led the author to suspect that salinity played a determining part in limiting the species because the only factor likely to exhibit a reasonably constant difference throughout this territory and throughout the season was salinity. This year (1915) a study of the salinity of the water in relation to these species of larvæ in both laboratory and salt marsh by Dr. F. E. Chidester[2] has shown that highly saline water (10 to 15 per cent) is favorable to the growth of the wrigglers of the white-banded salt-marsh mosquito and injurious (deadly if sufficiently high) to the wrigglers of the brown salt-marsh mosquito, while only slightly salt water (6 to 8 per cent) is favorable to the latter and injurious to the former. The younger the larvæ the more acutely are they affected by the degree of salinity. Speaking broadly, we may say that the salinity of the marsh, especially near the upland, is lower in the spring than during any other part of the mosquito season and concomitantly the brown salt-marsh mosquito is dominant. Later in the season as the salinity of the water increases the white-banded species becomes dominant except where owing to a constant influx of fresh water the salinity is kept at a low point

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[1]Smith, John B., Report of the New Jersey State Agricultural Experiment Stations upon the mosquitoes occurring within the State, their Habits, Life History, etc. 1904.

[2]Chidester, F. E. The influence of salinity on the development of certain species of mosquito larvæ and its bearing on the problem of distribution of species. N. J. Agr. Exp. Sta. Bul. 299. 1916.

MIGRATION

The work of the late Dr. Smith[3] has served to show that the brown salt-marsh mosquito (*A. cantator*) and the white-banded salt-marsh mosquito (*A. sollicitans*) migrate for long distances from the places where they breed. Neither the cause nor the occasion of their flight seems to have been satisfactorily explained. Upon the former the work has thrown no light but on the latter some significant observations have been made. Mr. Eaton's[4] observations in Atlantic County serve strongly to indicate that these mosquitoes migrate considerable distances only with the wind, and with it only when the velocity is low—10 miles an hour or less with an optimum near to 5—and the relative humidity high. The author's own observations serve to confirm these conclusions. This, of course, carries with it the idea that immense numbers of mosquitoes fly out to sea. On this point he is unable to testify from personal experience, but it is a matter of common knowledge along the coast that boats at sea off the coast occasionally meet tremendous swarms of mosquitoes.

Early in the work of the county unit it became obvious that the source of the mosquitoes occurring in a particular county must be determined, for despite utmost efforts to control local breeding a pest of mosquitoes occasionally appeared in parts of the protected territory. It seemed apparent from Dr. Smith's 1904 report that he and his assistants were accustomed to trace salt-marsh broods from place of breeding to distant points through the medium of getting data from widely separated observers on the time when the mosquitoes first appeared in the observers' localities.

It occurred to the author that the tracing might be done very quickly with an automobile by starting in uninfested territory close to the infested area and collecting at regular distances—say, 0.5 of a mile to 2 miles—until the mosquito zone had been traversed and uninfested country found on the other side; this collection to be followed by a similar one pursued in a line at right angles to the first.

Two assumptions were, of course, necessary to the success of this plan, one of which is that the mosquitoes may be collected in daylight and the other that the direction of greatest density indicates the source of the brood. The collections were made in as nearly similar places as possible, especially as regards the character of the growth, and the relative number present was determined by using two small cyanide tubes and catching specimens as rapidly as possible for a definite period of time, then reckoning the catch on the basis of so many per minute.

In actual practice whenever the study began on the first appearance of the brood, these assumptions were found to be correct and many broods have in this manner been traced to their places of origin. At least three important results followed the discovery and use of this method, the first was the finding of immense breeding areas in the Hackensack Valley salt marsh in sections hitherto

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[3] Loc. cit.

[4] Eaton, Harold I. Second Ann. Rpt. Atlantic Co. Mosq. Exter. Com., p. 39-43. 1914.

thought to be free of breeding, the second was the uncovering of inefficiency in the control of salt-marsh breeding on certain especially dangerous areas, and the third a determined and apparently successful effort to eliminate the breeding places thus discovered.

Scarcely had this method of discovery of salt-marsh breeding been well started before it became necessary to find the source of a brood of the house mosquito (*C. pipiens*) which in spite of effort to control local breeding continued to infest North Elizabeth in Union County. It was quickly found that no progress could be made by day collections and that a difference in the hour when the collections were made gave such a difference in the number caught that determination of density by serial collections covering several hours was impracticable. Accordingly, a sufficiently large number of inspectors were furnished by Union and Essex Counties to cover a line extending through North Elizabeth to and through South Newark to the sewage-charged salt marshes, each man collecting for 20 minutes at three stations, one-quarter of a mile apart from each other, between 8.00 p. m. and 9.30 p. m. The following evening in the same manner a line from the marshes running at right angles to the first was collected. In this instance the weather of the two evenings was sufficiently similar to render the results comparable but generally it would be better to have enough inspectors to collect both lines at the same time.

A careful study of the collections showed a zone of house mosquitoes extending from North Elizabeth to the Ebling section of the Essex County salt marsh, a distance of at least 2.5 miles, with practically steadily increasing density as the marsh edge was approached.

Examinations of the marsh, which was heavily charged with sewage, showed enormous numbers of *C. salanarius* and *C. pipiens* with small numbers of *A. sollicitans* and *A. cantator* in larval and pupal stages. The question has been raised as whether supposed house mosquitoes were not really *salanarius*. Undoubtedly, both *C. pipiens* and *C. salanarius* were component portions of the zone, but the smaller portion seemed to consist of the smaller, darker laukier form which was thought to be the latter. It seemed only fair to conclude that while *C. salanarius* played a part in forming this mosquito zone, *C. pipiens* was clearly shown in this case to migrate a distance of 2.5 miles from the place of breeding.

Later the president of the Essex County Mosquito Extermination Commission, Dr. Ralph H. Hunt, and the chief inspector of that organization, Mr. John W. Dobbins, demonstrated in a similar manner a zone of the house mosquito extending from the Frank Creek section of the Kearny marsh to the western edge of Branch Brook Park in Newark, a distance of 1.75 miles.

It is interesting in this connection to note that the city of New Haven, Conn., was for three years troubled during the latter part of the season with *C. pipiens* which bred in the dye-charged waters of West River.[5]

These facts must not be taken to indicate that the house mosquito normally migrates such distances. As a matter of fact, much study of this species on the wing indicates that save when

[5]Britton, W. E., First Ann. Rpt. N. J. Mos. Exter. Assoc., p. 71.

bred in enormous numbers over many acres of sewage-charged water, its distribution is "pocketed", by which we mean that areas of great density are small and isolated from each other, showing clearly that slight, if any, migration has taken place.

The discovery of this characteristic "pocketed" distribution of the house mosquito led the writer to wonder whether a careful charting of the mosquitoes on the wing twice each week would not

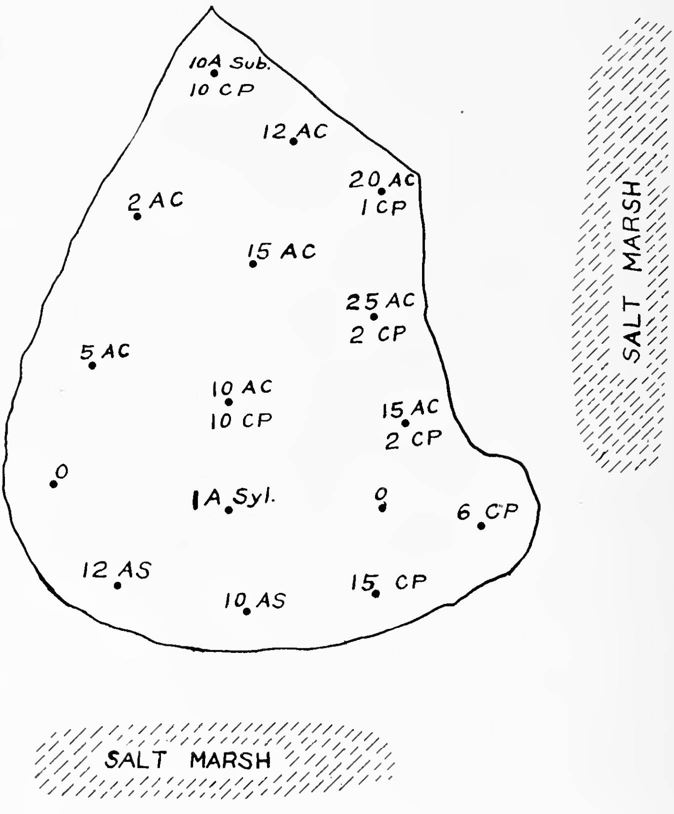


Fig. 1.—A diagram to illustrate the method of determining mosquito conditions by evening collections of mosquitoes on the wing. The area inclosed in the solid black line is protected.

* = Collection stations.

Numerals = number of mosquitoes caught at each station.
AC = the brown salt-marsh mosquito (*Aedes cantator* Coq.,).
AS = the white-marked salt-marsh mosquito (*Aedes sollicitans* Wlk.).
A sub. = the brown woods mosquito (*Aedes subcantans* Felt).
A syl. = the fresh-water swamp mosquito (*Aedes sylvestris* Theob.).
CP = the house mosquito (*Culex pipiens* Linn.). Let us analyze this diagram and see what it means for each species. The brown salt-marsh mosquito shows heavily along the eastern border and decreases *regularly* to the west and northwest. Evidently a brood had invaded the area from the eastern border. Likewise a heavy infestation of the white-marked salt-marsh mosquito appears along the southern border and decreases *regularly* to the northward. Evidently there has been an invasion of this species from the southward. The distribution of the house mosquito is *irregular,* clearly indicating that overlooked local breeding is responsible. The occurrence of 10 brown woods mosquitoes at one collection station indicates the existence of local breeding. The occurrence of 1 swamp mosquito is too slight to be significant.

lead to the discovery of these pockets in their incipiency, and in time to prevent the emergence of a number of mosquitoes sufficient to give the householders trouble. While temporarily in charge of the mosquito control work in Passaic County during the late summer of 1914, opportunity to test the idea arose. The semi-weekly collections were promptly charted and the pockets of *C. pipiens* thus indicated were promptly investigated for breeding. In every case, as he remembers it, some special breeding place hitherto overlooked was found and abolished, with the result that the concentration of the house mosquito at that point promptly disappeared.

During August of 1915 the distribution of the swamp mosquito (*Aedes sylvestris* Theob.) exhibited unusual features. Standing pools almost everywhere in clay land sections of the state were found to contain larvæ of this species and for a time it was the dominant form. It will be interesting to note the effect of the tremendous egg-laying of late last summer on the early spring emergence of this species.

Suggested Method of Making Mosquito Collections

There is no occasion to begin making evening collections until the breeding conditions indicate that mosquitoes are beginning to get on the wing or some adults are discovered incidentally. In the spring when we have the salt-marsh, the woodland-pool, and the fresh-water swamp species to deal with, daylight collections will be satisfactory, provided they are made in the same manner, at the same time and in similar (preferably weedy or shrubby) places. When, however, as from early summer the house mosquitoes must be taken into consideration, the time of collection should be between 7.30 p. m. and 9 p. m. Each collector should spend at least 15 minutes in a place and one man may take care of two or even three places.

If the territory be large and the number of collectors small, one evening each week should be given to the county-wide collection and various limited portions of the territory should be attended to on the other evenings.

The number representing each species at each station should be determined on the following morning and the results set down upon a map of the area. If here and there over the map small isolated areas where mosquitoes are much thicker than elsewhere are found, these areas should without delay be most carefully searched for over-looked breeding. If areas of considerable size are found on the border or of large size well within the confines of the area, they should at once be further studied. If the species concerned belongs to the salt-marsh or fresh-water swamp or woodland-pool, daylight collections will serve to get at the facts, but if the house forms are to blame the examinations will have to be made in the evening. In either case, two lines of collection should be made—one running through the dense zone in one direction and the other at right angles. The direction in which the number of mosquitoes caught grows larger is the source of the brood and if the tracing is done promptly the larvæ or pupæ, or pupal shells will be found where the brood in question matured. If not promptly traced the location of the source of brood may be found to be impossible.

It is thought that by use of these methods of collection the

density of the mosquito fauna may be expressed in terms of so many mosquitoes a minute or other period of time, and that the number per minute, quantities above which mean trouble to the householder and below which mean freedom from trouble, will soon be determined for each of the species concerned. It is thought that experience will soon define the increase in number, which means that the fresh-water species, especially the house mosquito, is breeding unchecked and that more careful examination must be made. It is further thought that this increase may be detected early enough to find the breeding and to eliminate it before the density of the fresh-water mosquito fauna becomes sufficient to trouble the householder. It is thought that the practice of these methods will enable the exterminator to run down accurately the breeding places from which the invasion of migrational mosquitoes come and thus to take the first necessary step toward their elimination.

DRAINAGE

Up to 1912 very little drainage for mosquito control purposes had been placed on the upland and that on the salt marsh consisted of the 10x30-inch trenching with natural or artificial outlets as the case demanded, of filling the salt holes with sods taken from the ditches, of trenching to a central hole, or sump, and of cutting systems of parallel ditches connected with each other but without outlet.

Upland Drainage

Beginning in 1912 the county mosquito commissions have cleaned sluggish brooks, drained stagnant pools and swamps, stocked others with fish, and filled cisterns, cesspools and lot pools.

In the operation of cleaning brooks the bottoms have been regraded so as to permit a regular flow of the water, the sides have been cut down in such a fashion as to make them perpendicular and to render it difficult for grass to obtain a foothold. In the treatment of pools and swamps the effort has been to remove the water. Usually open ditches cut with ordinary picks and spades have been used but in some cases excellent tile drains have been installed.

It has been necessary to repair work on cleaned brooks and open ditches each year for the frost and high water cause the banks to cave and the grade to lose its evenness.

It can not be said that ditching on the upland has exhibited any marked advance in methods.

Salt-Marsh Drainage

Ditching

On the salt-marsh however, it has become plain during the last three years that no salt marsh is so well drained that it will at all times be free from mosquito breeding. There are times when, owing to high tides, continued rain, and cloudy weather (during which the rate of evaporation is greatly lowered), the water derived either from high tide or heavy rainfall or from both fails to be drawn off in time to prevent the maturing of the last remnant of the brood. Moreover, it may be said that the ditch mouths become plugged with sand or seaweed through the action of the waves and that by one means or another the ditches farther up in their courses become plugged with pieces of sod, accumulations of hay, and other rubbish.

It can be said, however, that during the past three years no case has come to the author's knowledge in which the 10x30-inch trenching of the ordinary high-lying salt marsh has failed to eliminate all but a small percentage of the brood which started.

The apparent inability of the ditching to afford complete control of breeding has demonstrated the maintenance of a patrol of the drained salt marshes throughout the mosquito breeding season, as one of the measures necessary to successful mosquito control work.

The greatest differences of opinion relative to the amount of trenching necessary to free an acre of breeding salt marsh from danger have existed, and to a considerable extent still exist. An attempt to discover the cause for this difference quickly reveals that each opinion is based on the particular area or areas of salt marsh with which the persons expressing them have had to deal.

Some marshes, owing to a larger percentage of the area being filled with holes and depressions in which the high tide or rain water is retained, require more extensive drainage than others. Furthermore, some marshes are protected from the tide by dikes and the natural drainage water is removed by tide sluices or even by pumps, and require on that account less trenching than would otherwise be the case. Other marshes are very wide and very poorly supplied with natural water-ways into which the primary trenching may be opened, and require on that account a larger amount of drainage, the extra amount being necessary in cutting outlets for the primary system.

The estimated requirements range from 90 to 600 linear feet of 10 x 30-inch ditching, or its equivalent, per acre. As a matter of fact, only rarely is the former figure practicable and then under especially favorable conditions, and never on the New Jersey salt marshes has the latter figure been reached. It seems probable that between 200 and 300 feet is the real average. To this must be added an amount of hole filling and shallow spurring which will add about 10 per cent to the acre cost. Fortunately, large portions of the salt marsh, particularly in the southern part of the state are so low-lying and open to the tide as to be swept by every tide which is a little higher than the ordinary, and are on that account so free from breeding as to require no drainage. In a given area which includes a considerable amount of this kind of land, the required number of feet of drainage per acre will be materially reduced.

The plan of trenching has not undergone marked changes. By 1912 two general plans were in use—the first of which might be called the parallel system, and the second, the pool-connecting system. The former was the one generally in use while the latter was thought to be adapted to particular conditions. In the parallel ditching scheme the territory to be drained was divided into districts on the basis of the possible outlet and each block of territory crossed by parallel ditches, lying sufficiently close to remove the surface water. Holes and depressions were spurred into these parallel ditches or filled with sod or other material. In the hole-connecting scheme ditches were run from one hole to another and finally into one or more outlets. It was held that such a plan

was most practicable where the marshes were very full of salt holes. The experience of the last three years has clearly pointed out the superiority of the parallel ditching and the hole-connecting plan has been practically abandoned.

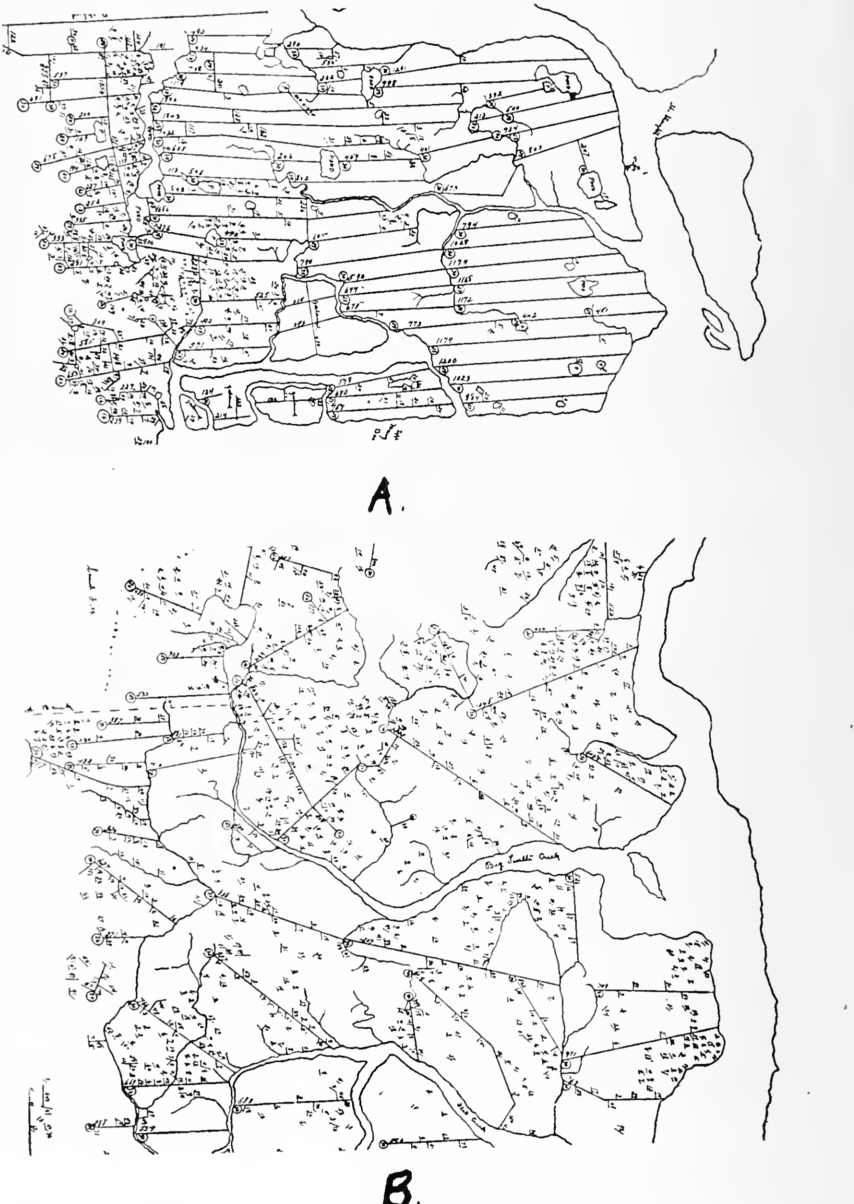
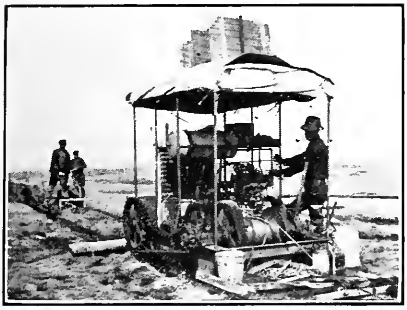


Fig. 2.—Parallel (A) and hole-connecting (B) schemes of ditching.

Early in the salt-marsh trenching it was recognized that the type of outlet was of supreme importance and recent experience has served to confirm this notion. The greater the tide drop and

the shorter the ditch the greater is its efficiency and its ability to keep clean. Every ditch should have a strong tidal outlet and no ditch depending on a single outlet should be over one-quarter of a mile long.

The machinery used in cutting ditches has undergone some important changes. The hand tools have made little if any advance. The Manahan and the Skinner types of spades are still the prevalent tools and are so covered with patents that the trenching of the marsh by anyone not possessing the right to use these



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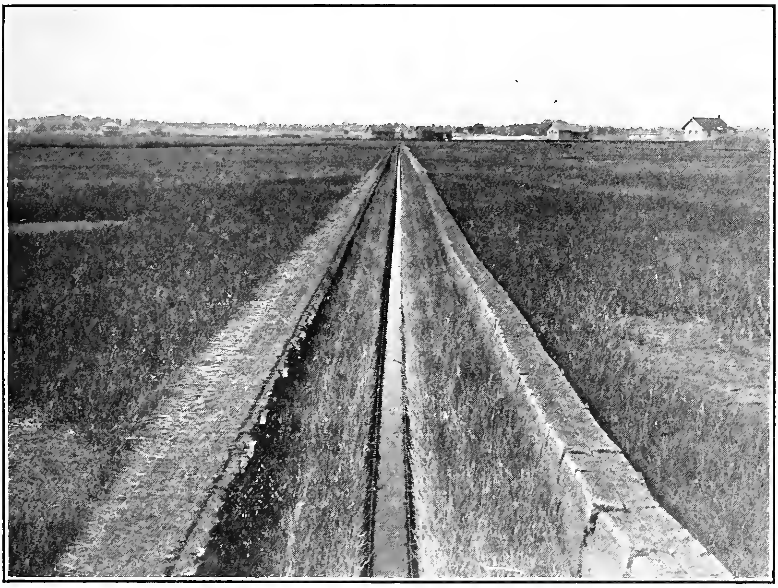

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Fig. 3.—Eaton ditcher. (Photos by Atlantic Co. Mos. Exter. Com). (A) Near and front view of power plant with plow in distance; (B) Near and rear view of the plow showing the ditch and way the sods are disposed of; (C) A ditch cut by the Eaton ditcher.

tools is both difficult and expensive. Recently, Mr. Harold I. Eaton has invented a practicable sort of hand spade but as a patent will be placed upon it the general public does not seem to be in a way to benefit by it materially.

A power machine has been invented by Mr. Eaton which unquestionably trenches the marsh with such ease and speed as to make a notable reduction in the cost of ditching. Essentially the machine consists of a gasoline power plant placed on a pair of 12-foot long, 12-inch wide and 2-inch thick planks that are set within 5 feet of each other and strongly bound together with crossties. The front and rear ends of the machine each bear a revolving drum, upon which a 500-foot ¾-inch steel cable is wound. When the power plant must be moved forward or away in another direction the anchor to which this front cable is bound is carried out in the desired direction and thrown into the sod. The power is then applied to the drum and the plant is drawn up to the anchor.

The plow or trencher consists of two 12-foot long, 10-inch wide and 2-inch thick planks set parallel and 10 inches apart. Suspended between these planks are two cutters. The point of the forward one is 15 inches below the under sides of the planks and the point of the second 30 inches below. As the machine is pulled forward each cutter shears out and brings up a piece of sod 10 inches wide and 15 inches thick which it deposits as a long ribbon on one side of the ditch. This plow is attached to the power plant by a 500-foot steel rope which is wound up on the rear drum, while the power plant is standing anchored ahead.

With a machine of this sort, which can be had for $1750, and 5 men it is possible to cut 3000 feet of trenching a day and in some cases more.

Competition and the invention of this machine have cut the cost of ditching from 2½ cents a linear foot in 1912 to less than 1½ cents, and are bound to bring it lower yet. The operating and up-keep cost of ditching with this machine, as shown by cutting hundreds of thousands of feet in the past two years, does not exceed one cent a linear foot.

Diking and Tide-gating

During the last three years it has become evident that while the 10 x 30-inch trenching serves well for the ordinary type of salt marsh, it is wholly inadequate to protect marshes that are badly shut-in and low lying. This was well illustrated on the Essex County marsh, where in 1914 in spite of more than one million feet of trenching on less than 4000 acres, an unusual combination of continued high tide, heavy rainfall, and cloudy weather permitted the emergence of a tremendous brood.

To protect areas of this type, diking and tidegating were undertaken. The Essex County commission was the first to try this method of preventing mosquito breeding. The idea seemed to this organization to be so practicable that it employed Mr. James E. Brooks of Glen Ridge as a consulting engineer and instructed him to prepare plans. Mr. Brooks examined the method of diking employed in the Hackensack Valley and along the coast of Delaware Bay for agricultural purposes, and finally devised a type of dike and sluice gate that have had two years of trial, and during that period have proven satisfactory.

Before Mr. Brooks was employed and later while he was pre-

paring his plans, Mr. John Dobbins of Newark, the chief inspector of the Essex County commission, enclosed a limited area of bad breeding sewage-charged salt marsh with a low mud dike in which the simplest type of sluice gates was set. The effectiveness of this preliminary work in drying out the previously inaccessible marsh was such as to justify the undertaking of more extensive work.

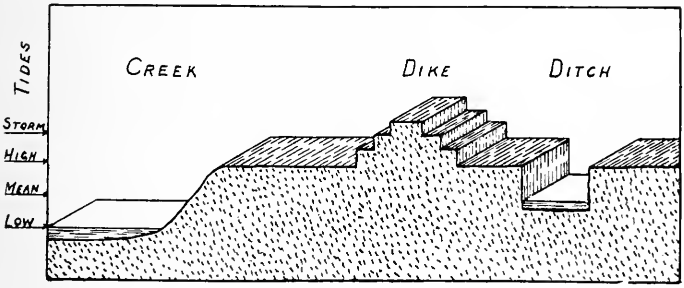


Fig. 4.—Diagram of a cross-section of a dike. (Prepared by Mr. James E. Brooks.)

When Mr. Brooks' plans were ready they called for a strong sod dike with a mud core and for substantial permanent sluice gates. For the benefit of persons who may have to meet similar problems necessary space will be taken to explain the nature of this dike and of the sluice gates.

The height of the dike was made to depend upon the height of the tide it was expected to keep out. In this case the dike was built to an elevation of 7 feet above mean low tide which was one-half of a foot higher than the previously recorded highest tide for the season of 1914. The intention was to build it high enough to keep out all but the very highest of high tides, the theory being that these extraordinary high tides come so rarely, and at such times of the year that fencing them out is unnecessary.

The dikes as they were built stood 3 feet above the meadow surface, were 2 feet wide at the top and 6 feet wide at the bottom. Anticipating a shrinkage of about 25 per cent, the crest was made about 1 foot higher than the elevation called for.

When the construction of the dike began, a trench 10 inches wide by 20 inches deep was cut along the line to be occupied by the structure, and the sods taken out utilized in making the dike. A row of sods composed of pieces approximately 10 inches wide, 12 inches high and 26 inches long was laid on each side of this trench with the grassy ends out enclosing a space 20 inches wide. Mud was then tamped into the trench until its surface was flush with the upper surface of the sod layer. Then another layer of sod composed of pieces 10 inches wide by 12 inches high by 24 inches long was placed on top of each of the two other layers. Again the grassy ends were out but the ends of the upper layer were 6 inches nearer the dike center than were the ends of the lower layer. The central cavity thus formed was tamped full of mud. Then a third layer of sod was placed on the second in a similar fashion with a similar approach to the center. The space formed between the two parts of the layers was tamped full of mud. In some cases the dike thus constructed was covered with a

A

B

C

D

Fig. 5.—Dike in process of construction. A. Cutting the preliminary trench; B. Tamping in the mud core; C. Gang at work on dike construction; D. Completed dike as it looked during the following summer. (Photos by Union Co. Mos. Exter. Com.)

layer of sod while in other cases the crest was simply rounded up with mud.

The sod and the mud for making the dike came from the preliminary trench and from a supply trench which was dug inside the protected area about 8 feet from the base of the dike. In some cases a supply trench was dug on each side of the dike. In every case the supply trench was of uniform width, did not exceed 3 feet in depth and was properly connected with adequate outlets.

During the summer of 1915 the grass in the sods grew vigorously and transformed the dike into a wall of green. The sods used in capping the dike dried out and separated until they looked

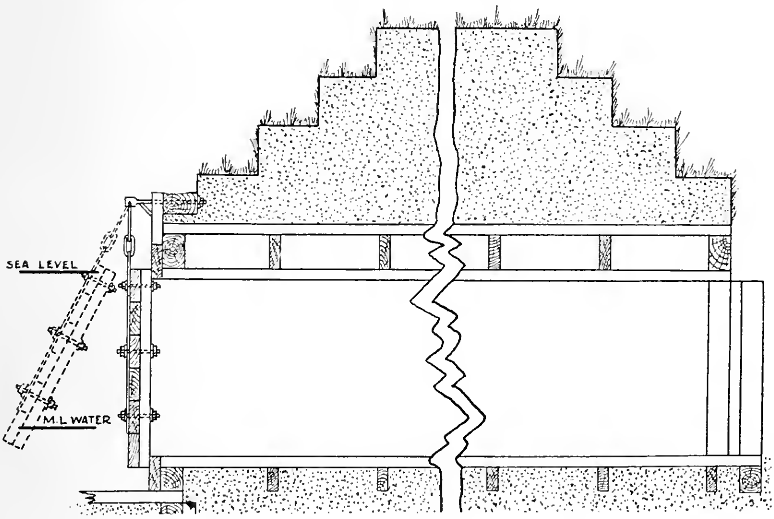


Fig. 6.—Diagram of sluice box and tide gate. (Prepared by Mr. James E. Brooks.)

like the battlements on a wall, and the layer became useless as a means of keeping water out. The mud cap settled down and formed a continuous solid cap serving much better the purpose for which it was intended than did the sod layer.

Some dikes have been constructed entirely with mud but always in places where sod was not available. In such instances the mud has been scooped from a trench back of the dike (forming a ditch paralleling the work and giving useful drainage), and piled up until a dike of requisite height with due allowance for shrinkage had been built, which was 2 feet wide at the top and as broad at the base as was demanded by the normal angle of repose. This type of dike does not withstand the weather or the water as well as the sod type but is efficient if carefully looked after.

At points where streams or larger ditches cross the dikes sluice boxes and tide gates were introduced. The largest sluice box used measured inside 3 feet high, 6 feet wide and 24 feet long. It was made of 2-inch lumber nailed to outside ribs at distances of 18 inches apart. The box was set on 2 rows of 2-inch sheet piling and then covered with soil. A large heavy wooden door

was suspended over the down-stream end of the box to serve as a tide gate. The following specifications have been used in the construction of sluices employed as an outlet for a large creek which at the point where the gates were introduced was 75 to 80 feet wide.

1. All sluices shall have an inside measurement of 6 x 3 feet and shall be built of 3-inch tongued and grooved long-leaf-pine, free from knots or serious blemish; they shall not be shorter than 15½ feet and shall extend from the outside of the dike facing back under the dike. These boxes shall be stiffened with 4 x 5-inch ribs bolted at each corner with a ½-inch bolt properly washered and drawn up with a satisfactory nut. These ribs shall be placed around the outside of the box fitting it closely at distances of 18 inches apart. The first and last shall be made flush with the ends of the box. The planking shall be firmly spiked to these ribs with 6-inch galvanized spikes. The top of the box shall be covered with 2-inch long-leaf-pine spiked on the top of the ribs.

2. The dike shall be faced on the river side with plank piling for 120 feet at the mouth of Kingsland Creek. This facing shall consist of 3-inch long-leaf-pine planking, free from knots and serious blemish, not less than 14 feet long driven in until the top shall be one foot below the level given for the top of the dike. If the tops of the piles are splintered, split or broomed by driving, they shall be cut off below the lowest point of injury. In any case the cut of ends shall not be such as to make length of pile less than that provided. The top of the piling shall be even and bound together by running a 3 x 8-inch stringer along the outside and inside surfaces.

Each pile shall be bound to this stringer by a ½-inch bolt which shall be furnished with large washers and a suitable nut. The opening for the sluice boxes shall be made closely to fit the box. The cut ends of the piling above the box shall be bound together by 3 x 8-inch stringers which shall extend one on the inside and one on the outside from a point 2 feet beyond one edge of the opening to a point 2 feet beyond the opposite edge of the opening. These stringers shall be set flush with the cut ends of the piling and each pile which they cover shall be bound to them by a ½-inch bolt properly washered and fitted with a nut. The cut ends of the piling below the box shall be bound together in the fashion above described.

3. All sluice boxes shall be laid on 2 extra rows of sheet piling composed of 3-inch long-leaf-pine closely set together. The planking shall be 10 feet long and driven in until the top shall be 9 inches below mean low tide. The above provision regarding injury due to driving and its correction shall be observed here. Each row of this sheet piling shall extend 4 feet each side of the sluice boxes. Each row shall be bound together at the top in a fashion similar to that provided for the dike facing, and the piling at the sides of the boxes shall extend up through the stringers one foot and the rectangle thus formed shall be made closely to fit the boxes.

4. At the sluice boxes the inner side of the dike shall be protected by sheet piling wing-walls made of 2-inch long-leaf-pine without serious blemish, 14 feet in length driven in until the top is one foot below the level of the dike. The above provision re-

garding injury due to driving and its correction shall be observed here. They shall be bound together at the top in the same fashion as the dike facing, and shall extend 6 feet each side of the sluice boxes.

5. The river side of each sluice box shall be furnished with a 7 x 4-foot gate made of tougued and grooved white pine. It shall be composed of two layers, the inside one being made of 3-inch 7-foot long planking and the outside one of 2-inch 4-foot long planking laid at right angles to one another and firmly spiked together. The gate shall be hung in front of the opening with a suitable link hinge so that it will readily open with the falling tide and readily close with the rising tide.

Fig. 7—Photograph of a tide gate and sluice. (Photo by Union Co. Mos. Exter. Com.)

Lighter sluice gates have been employed but no larger or heavier ones. If the capacity of more than one was needed duplicates have been installed. This plan has been followed because gates larger than this have elsewhere proven difficult to keep in working order.

Recently Mr. Brooks has devised another type of sluiceway and tide gate, which the writer has since found to have been anticipated, which he believes to be superior in many respects to any of the others. In this case no box is constructed but heavily timbered bulkheads are built into the stream until they stand within approximately 6 feet of each other. To render their relation to each other constant they are bound together by heavy cross timbers. At a point half-way between the two ends, a pair of heavy 6 x 6-inch well braced timbers are set down in such a fashion as to form the support and resting place for the tide gate. Of course, the joints between each of the upright posts and the bulk-head against which it stands and between the lower cross timbers and the bottom are made tight.

The tide gate is suspended from a cross timber located well above extreme high tide, and hangs against the upright posts. At each end the bulkheads are fitted with slots in which planking

can be dropped to form a coffer dam. The water between the two bulkheads has merely to be pumped out, when these dams are in place, to expose the gate for repairs and the sluiceway for cleaning. The top of the sluiceway thus formed is left open. Mr. Brooks holds that the greater ease with which this type of gate can be kept in good working order is sufficient to warrant its adoption.

The problem of preparing a proper dike, sluice boxes, and tide gates for draining a given area is an engineering one. Suffice it to say that the trenching, diking, sluicing, and tidegating must

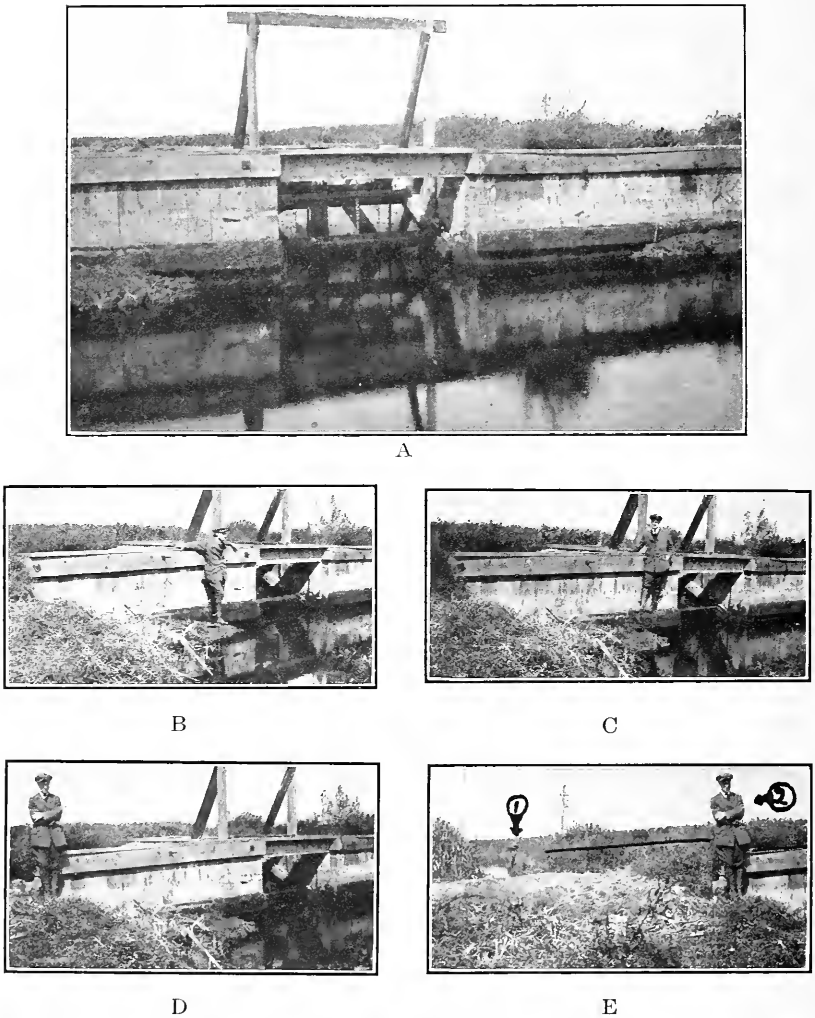


Fig. 8.—Relative level of water on the protected area as compared with the tide. A. Sluice and gate in Maple Island Creek. B. Same just before the sluice begins to discharge. C. Same showing medium tide level, see the level of Mr. Walden's boot soles. D. Same showing extreme high-tide level, see level of Mr. Walden's boot soles. E. Same showing relative level of water inside and outside the dikes under extreme high-tide conditions, (1) shows Mr. Walden standing at water level inside the dike and (2) shows the same man standing at the level reached by the water outside the dike under extreme high tide.

be so planned as to keep out all but the most extraordinary high tides and to free the surface from water within 5 days after a heavy rainfall.

Salt marshes protected in this way, at certain times of the year are subject to mosquito breeding in the drainage ditches. If the ditches are not sewage-charged, opening the tidegates and allowing the tide water to flow in usually brings a large enough number of killifish to eliminate breeding. If the trenching is so arranged that the water it contains may be flushed out without escaping into the meadow over the surface of the ditches it is likely that introducing the tide regardless of the presence of fish will have a beneficial effect. If the ditches are heavily sewage-charged the use of fish appears to be out of the question and any value that can come from flushing must come through the accelerated movement of the water. As a matter of fact, the author is inclined to believe that elimination of breeding in the ditches of diked areas when sewage-charged, is a matter of removing the water by a pump or a matter of covering it with oil at regular intervals.

During the summer of 1916 Mr. John Dobbins, chief inspector of the Essex County commission worked out a new method for preventing mosquito breeding on an undiked salt marsh. Mr. Dobbins worked with a piece of rather high-lying meadow bordering on Newark Bay. He introduced small tide gates into the main outlet ditches without materially disturbing the 10 x 30-inch ditching which had already been established on the meadow.

When the monthly high tides came the water-table had been so reduced that the overflow was promptly absorbed by the dry soil and the ditches, and almost no trouble was experienced with breeding.

The cost of this addition to the usual drainage system depends upon the size and number of outlet streams that must be gated. To what extent the method will apply to marshes differing in type from this one, can not at this time be said, but its efficiency in this instance is such as to merit attention from all who have large areas of open marsh to protect from mosquito breeding.

Pumping

The need for pumps in mosquito control first became apparent in Hudson County where the railway grades and roadways had cut the marsh up into pockets, the satisfactory outleting of which was impracticable from the standpoint of cost. In the Kearny section of the marsh an area of this sort, which had its outlet through Frank Creek into the Passaic River, had shrunken until parts of the surface were scarcely above and perhaps in some cases below mean low tide, and had become charged with sewage from the creek which served as a sewer for the towns of Kearny and Harrison. The creek emptied into the Passaic River through an 8 x 12-foot concrete culvert 300 feet long running under the Pennsylvania Railroad and the Delaware, Lackawanna and Western Railroad tracks. Tidal water from the Passaic River was prevented from entering the creek by means of a pair of large sluice gates. Except where the trunk sewers entered, the banks of

Frank Creek were built up, but every heavy rainstorm served to send it over them and to keep the adjacent marsh soaked with sewage. By cleaning the creek, enough flow of water was obtained to keep the surface fairly free from breeding during ordinary dry seasons, but when heavy rainfall came the arrangements were shown to be wholly inadequate and large broods of mosquitoes developed.

It having thus become evident that some other step must be taken, the Hudson County commission decided to install a pump. A 12-inch low-head centrifugal electrically-driven pump was placed on the east bank of the creek at the lower end of this area, at a total cost of about $1300, and all the territory lying east of the creek amounting to about 700 acres was ditched to it.

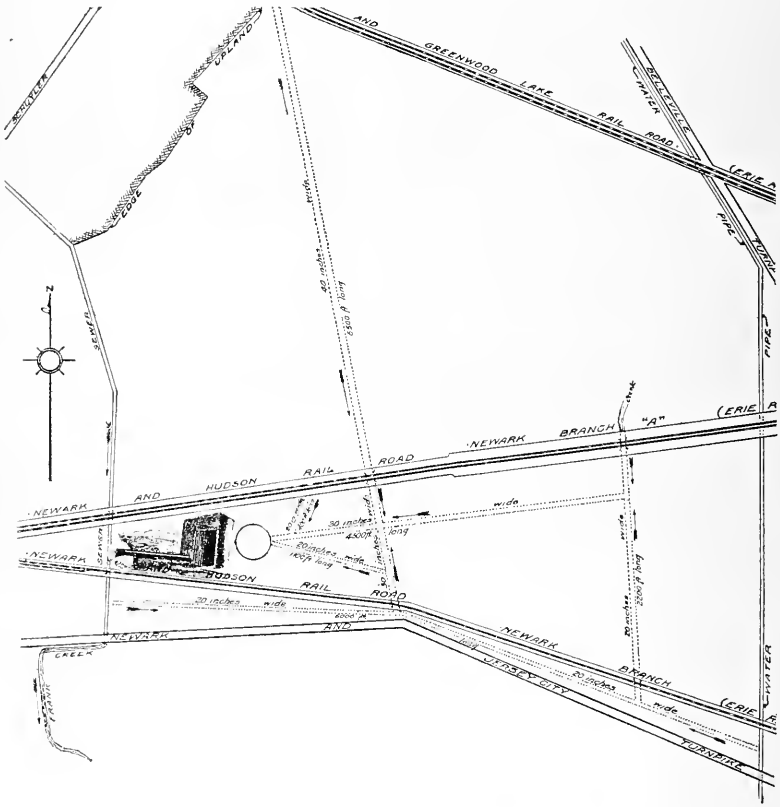
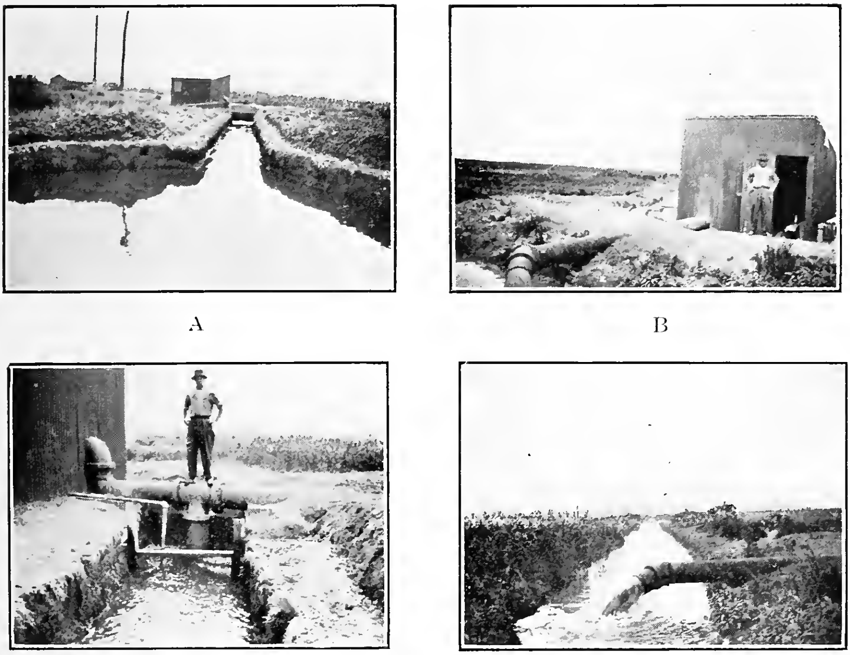


Fig. 9.—Diagram of Frank Creek area, showing ditching outlets and pumps.

It was quickly found that the pump could handle the water far more rapidly than the trenching could bring it, and in consequence of no considerable enlargement of the trenching scheme, the pump has not worked at full capacity except for brief periods. The maintenance and operation charge during the 1915 mosquito season averaged about $80 a month. In spite of the fact that the 200 acres lying west of the creek had to depend upon the sluggish over-filled creek for drainage and that the trenching on the eastern side was not adequate to bring the water down with sufficient

rapidity to permit prompt removal of surface water, and that the banks of the creek were not sufficiently built up to prevent the occasional spilling of sewage water over them, the area was freer from mosquitoes in 1915 than it had been either of the two seasons previous, although the season was as bad as or worse than either of the others. When more trenching has been cut to lead the water to the pump, when the 200 acres lying west of the creek are drained to the pump, and when the banks of the creek are built up so that the water cannot spill over, all breeding of mosquitoes should be eliminated from the areas served by the pump.



A B C D

Fig. 10.—Twelve-inch centrifugal pump, which was installed to drain an area of marsh slightly below sea level. (Photos by Hudson. Mos. Exter. Com.)

A smaller area, amounting to about 150 acres lying just south of the one previously discussed and depending upon Frank Creek for its outlet, was served in 1915 by a high-head 4-inch centrifugal gasoline-driven pump that cost about $600 to install. It was operated and maintained in such a manner as to prevent serious breeding of mosquitoes in that area. This area is not sewage-charged and depends for its supply of water upon rainfall and possibly a small amount of seepage from the Passaic River.

Whether an area shall be pumped, what type and what capacity of pump shall be employed, what trenching must be used to bring the water to the pump and to take it away, are engineering questions and persons having to answer them will do well to secure the advice of a competent engineer.

LARVICIDES

The work on this subject thus far has seemed to indicate fuel oil as the best larvicide for general use. Fuel oil is a variable product and the question as to what grade is best naturally arises. The grades range from a light straw yellow to almost or quite black. The former disappears too rapidly and the latter forms a film with too great difficulty. The best results apparently follow the use of an oil that is light in color but which betrays con-considerable viscosity. It is possible to obtain oils having these characters. The author has been furnished with such types by the Standard Oil Company. In summing the matter up, we may say that any oil which flows readily, is cheap, and does not disappear too quickly will be fairly satisfactory. The method of application depends on the viscosity of the oil and the size of the pool treated. A very viscous oil should be delivered as a mist by a sprayer, but light oils may be satisfactorily applied with a common garden sprinkling pot if the pool is small, or as a slender solid jet under pressure if the pool is large.

Under conditions where immediate killing of the larvæ is essential, a substance such as the larvicide made and used by the Isthmian Canal Commission seems best. Both these substances, however, have certain glaring defects which render them anything but ideal larvicides. Both substances destroy plant growth and make treated pool unsightly, and both disappear in a short time.

The really satisfactory larvicide should be cheap in cost, reasonable in the expense of application and should remain effective in the pool for a season, reappearing as often as the pool refills with water. It should not be deadly to plants and not seriously injurious to the higher animals and man. Perhaps the ideal larvicide as thus defined will not be found, but room for improvement on what we already have is so great that a serious study of the problem has seemed worth while. The report which follows represents the barest beginnings.

Sulfuric Acid

Because of its toxic nature, its cheapness and its availability, sulfuric acid was selected for testing. A series of experiments served to show that under laboratory conditions fully grown larvæ of *Culex pipiens* Linn. perished in 2 days, in a mixture of 1 volume of sulfuric acid testing 1.84 sp. gr. to 2000 volumes of distilled water. Another series served to show that 1 volume of acid to 1000 volumes of water testing nearly 3 per cent salinity (concentrated sea water having been added to the distilled water) destroyed larvæ of *A. cantator* from 1/8 inch long up to maturity in 2 days' time. Still another series of laboratory experiments served to show that 1 volume of acid added to 1000 volumes of sea water showing 10 per cent salinity destroyed in 4 days the larvæ (ranging from 1/8 inch long up to maturity) of *Aedes sollicitans* Wlk. Obviously sulfuric acid was effective at dilutions sufficiently high to render its use practicable from the standpoint of cost.

The next step was to determine whether it disappeared from treated pools, and at what rate. For the preliminary study of this phase of the problem a small pool 8 feet wide by 12 feet long was

selected. The bottom and sides were of red shale soil and a considerable amount of old troughs and leaders had been thrown into it. Samples taken immediately after treatment showed 9.31 parts per 10,000 parts of water. Samples taken 4 days later showed 2.45 parts per 10,000. Samples taken 18 hours later showed 2.00 parts per 10,000. Samples taken 2 days later showed 1.96 parts per 10,000. At this time evaporation had greatly lowered the level of the pool. Samples taken 1 day later following a small rain showed 1.47 parts per 10,000. Samples taken 17 days later showed 0.16 parts per 10,000.

In 3 weeks, with never enough rain to fill the pool to overflowing, starting with it brimful, the acidity dropped from 9.31 parts per 10,000 to 0.16 parts per 10,000. Thus it appears that the acid as an efficient treatment lasted no longer than fuel oil.

Not being satisfied with our ability to prevent all artificial variations, such as those occasioned by throwing pieces of sheet iron or tin cans into the pool, four wooden wash tubs were secured for a further test. One was filled three-quarters of the way to the top with red shale soil, another one-half way to the top, another one-quarter the way to the top, and another given no soil whatever. The tubs were placed in the yard just back of the Entomology Building. It was planned to acidulate distilled water at the rate of 1 part of acid to 1,000 parts of water and to fill all tubs. Through a misunderstanding an assistant filled the tubs with water, estimated the volume, and acidulated on that basis at the rate of 1 volume of the acid to 1,000 volumes of water. The experiment was set on September 18 and followed until October 15. On September 19 samples from the tub with most soil showed 1.6 volumes to 1,000 volumes. Samples from tub half-filled with soil showed 1.6 volumes to 1,000 volumes. Samples from tub one-fourth filled showed 1.3 volumes to 1,000 volumes. Samples from tub without soil showed 1.3 volumes to 1,000 volumes.

Samples taken October 15 showed for the first tub, 0.014 volumes to 1,000 volumes, the second 0.45 volumes to 1,000, the third 0.52 volumes to 1,000 and the fourth 1.2 volumes per 1,000 volumes.

The tub experiment is thus seen to confirm the results obtained at the pool in that it shows a strong diminution of the acid when in contact with soils. The detailed data shows that the fall in acidity was steady—much steadier than that in the pool.

Inasmuch as practically all pools are in soil or other substance which may combine with sulfuric acid and in many cases contain objects which the acid may attack, it seems unlikely that sulfuric acid can have any great importance as a larvicide.

Chlorine

A preliminary investigation of this substance as found in bleaching powder was undertaken principally because of its cheapness. Dr. Smith had already shown that it could be used as a larvicide of limited application. By a series of laboratory tests it was quickly found that 0.5 gm. of the commercial bleaching powder to 1000 c. c. of water would destroy all stages of *C. pipiens* larvæ. A study of its persistance was then undertaken. To jars of distilled water on September 23 commercial bleaching powder was added as follows: Jar No. 1, 1 to 100; Jar No. 2, 1 to 1000;

Jar No. 3, 1 to 10,000. Samples taken September 23 showed for No. 1, 73.6 parts of chlorine per 100,000; No. 2, 6.6 parts per 100,000, and No. 3, 0.6 parts per 100,000. Samples taken October 1 showed for No. 1, 67.8 parts; No. 2, 6.0 parts and No. 3, 0.0 parts. The reduction continued steadily until October 13 when the readings were discontinued. At this time No. 1 showed 30.4 parts per 100,000 and No. 2, 2.0 parts per 100,000.

All things considered the chlorine showed remarkable persistence but, of course, was constantly disappearing. When in addition to its habit of disappearing from distilled water in glass vessels, we consider its habit of attacking just such substance as would be found in pools, it does not seem likely that chlorine can have more than a limited use as a mosquito larvicide.

Electrolysis

Early in the season the American Electricide Company of Washington, D. C., approached the Experiment Station with a proposition to destroy mosquito breeding and render the marsh uninhabitable for the mosquito by the passage of an electric current. This company was invited to make a demonstration at its own cost.

On Saturday, July 31, 1915, the machinery consisting of a gasoline-engine-driven dynamo, connecting wires, and electrodes was set up on the Linden Meadow near Grasselli, New Jersey, and a demonstration run made. Pools well stocked with nearly mature wrigglers of *A. sollicitans* were in easy reach. A line of several carbon electrodes was run along one edge of one of these pools and a line of metal electrodes along the opposite side, the two lines running parallel to each other and about 15 feet apart. For fully one hour the current was passed. The results are transcribed directly from the Entomologist's notes. "At 5.15 p. m., I examined the pool and found an abundance of living larvæ and pupæ but no dead ones whatever. At this time the grass was full of freshly emerged adults none of which seemed to be in any way inconvenienced by the treatment. On the afternoon of August 1 just 21 hours and 40 minutes after the electrolytic treatment ceased, I examined the treated pool and found the conditions as they were the previous day except that the number of larvæ had slightly decreased and the number of pupæ increased, as had the adults. On the morning of August 2 the pool was re-examined by a representative of Mr. R. W. Gies, chief inspector of the Union County Mosquito Extermination Commission, and no evidence whatever of killing found."

A report of our finding was promptly rendered to the company, representatives of which then expressed the intention of keeping the machine on the marshes and working the problem out.

Nitre Cake

This is a by-product of gun-cotton making and furnished to us by the Du Pont Powder Company. The saturated solution is weakly acid, requiring 1.59 c.c. of N/50 sodium hydroxide to neutralize 5 c. c. The larval tests with various strengths of this substance in distilled water indicated that nothing weaker than 1 to 100 could be depended on to kill, but the numbers used were too small. The pupæ survived in a saturated solution.

Date Due

SEP 7 1942			